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<b>1. AGENCY USE ONLY (Leave blank)</b>		<b>2. REPORT DATE</b> January 14, 2002	<b>3. REPORT TYPE AND DATES COVERED</b> Final Technical Report 1 Jun 97-31 Dec 00	
<b>4. TITLE AND SUBTITLE</b> VERY LOW FREQUENCY (VLF) REMOTE SENSING OF GRAVITY WAVES GENERATED BY THE AURORAL ELECTROJET			<b>5. FUNDING NUMBERS</b> G F49620-97-1-0468	
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<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Department of the Air Force AFOSR/NE 110 Duncan Avenue Room B115 Bolling AFB DC 20332-8050			<b>10. SPONSORING / MONITORING AGENCY REPORT NUMBER</b>	
<b>11. SUPPLEMENTARY NOTES</b>				
<b>12a. DISTRIBUTION / AVAILABILITY STATEMENT</b> <b>DISTRIBUTION STATEMENT A</b> Approved for Public Release Distribution Unlimited			<b>12b. DISTRIBUTION CODE</b> THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLIC RELEASE LAW AFR 190-12. DISTRIBUTION IS UNLIMITED.	
<b>13. ABSTRACT (Maximum 200 Words)</b> During the period of performance the VLF remote diagnostic technique was applied in order to characterize both the ambient and modified D-region when perturbed by atmospheric gravity waves generated by the auroral electrojet. The characterization involved VLF sub-ionospheric wave phase and amplitude measurements at four sites located in Alaska and four sites located along the east coast of the North American continent. A total of ten separate propagation paths were monitored. A large number of gravity wave events were captured that exhibited features consistent with impulsive generation by the auroral electrojet. Measured VLF sub-ionospheric wave amplitudes were perturbed by as much as 3 dB by the gravity waves. The measured VLF wave amplitude and phase perturbations were consistent with a vertical displacement of the D-region driven by the gravity waves. We conclude that gravity waves excited by the auroral electrojet can have significant effects upon the amplitude and phase of sub-ionospheric VLF waves.				
<b>14. SUBJECT TERMS</b> Gravity waves, sub-ionospheric VLF waves			<b>15. NUMBER OF PAGES</b>	
			<b>16. PRICE CODE</b>	
<b>17. SECURITY CLASSIFICATION OF REPORT</b> UNCLASSIFIED	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> UNCLASSIFIED	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> UNCLASSIFIED	<b>20. LIMITATION OF ABSTRACT</b>	

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**FINAL TECHNICAL REPORT**

**SPONSOR: DEPARTMENT OF THE AIR FORCE**

**SPONSER REF: F49620-97-1-0468**

**TITLE: VERY LOW FREQUENCY (VLF) REMOTE SENSING OF GRAVITY  
WAVES GENERATED BY THE AURORAL ELECTROJET**

**PERIOD OF PERFORMANCE: 06/01/97 - 12/31/00**

**PRINCIPLE INVESTIGATOR: PROFESSOR U. S. INAN**

**STAR LABORATORY, STANFORD UNIVERSITY**

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January 14, 2002

## SUMMARY

During the period of performance the VLF remote diagnostic technique was applied in order to characterize both the ambient and modified D-region when perturbed by atmospheric gravity waves generated by the auroral electrojet. The characterization involved VLF sub-ionospheric wave phase and amplitude measurements at four sites located in Alaska and four sites located along the east coast of the North American continent. A total of ten separate propagation paths were monitored. A large number of gravity wave events were captured that exhibited features consistent with impulsive generation by the auroral electrojet. Measured VLF sub-ionospheric wave amplitudes were perturbed by as much as 3 dB by the gravity waves. The measured VLF wave amplitude and phase perturbations were consistent with a vertical displacement of the D-region driven by the gravity waves. We conclude that gravity waves excited by the auroral electrojet can have significant effects upon sub-ionospheric VLF signal amplitude and phase.

## **FINAL TECHNICAL REPORT**

### **1. Contract Purpose**

The purpose of this contract (F49620-97-1-0468) was to carry out a program of technique development, data acquisition, and data analysis in order to characterize both the ambient and modified D-region when perturbed by atmospheric gravity waves generated by the auroral electrojet. The data was acquired at eight sites which were established and supported by the Parent contract F19628-96-C-0149-P00003. The data acquired at these sites consisted of measurements of the phase and amplitude of sub-ionospheric VLF signals transmitted by VLF communications transmitters operated by the United States Navy.

### **2. Period of Performance**

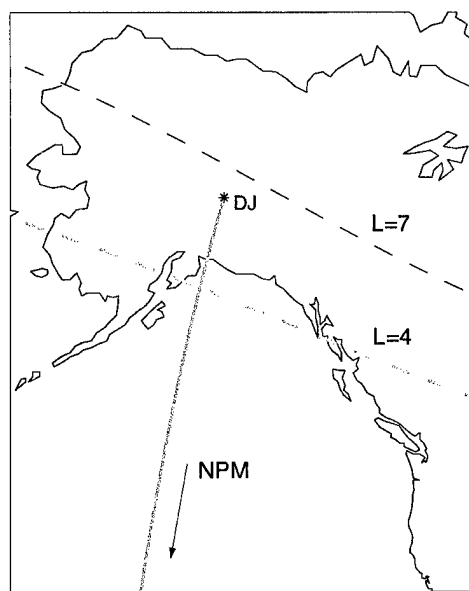
The original period of performance under this contract extended from June 1, 1997, through May 31, 2000. However, in order to better fit the academic schedule, a no cost seven month extension of the Grant was requested and granted. Thus the actual period of performance was June 1, 1997, through December 31, 2000.

### **3. Work Provided**

During the period of performance of this grant, Stanford University acquired sub-ionospheric VLF wave amplitude and phase data during atmospheric gravity wave events at each of the Alaskan and East Coast sites supported by the Parent contract. Instrumentation used for this task was developed and deployed under the sponsorship of the Parent contract F19628-96-C-0149-P00003. The gravity wave data was analyzed using general algorithms developed under the Parent contract and specific algorithms developed for gravity wave analysis. This work was reported in a paper delivered at the December American Geophysical Union in 1998 [Demerkol, *et al.*, 1998]. The complete citation for this paper is given in Section 4.

#### 4. Results of atmospheric gravity wave study

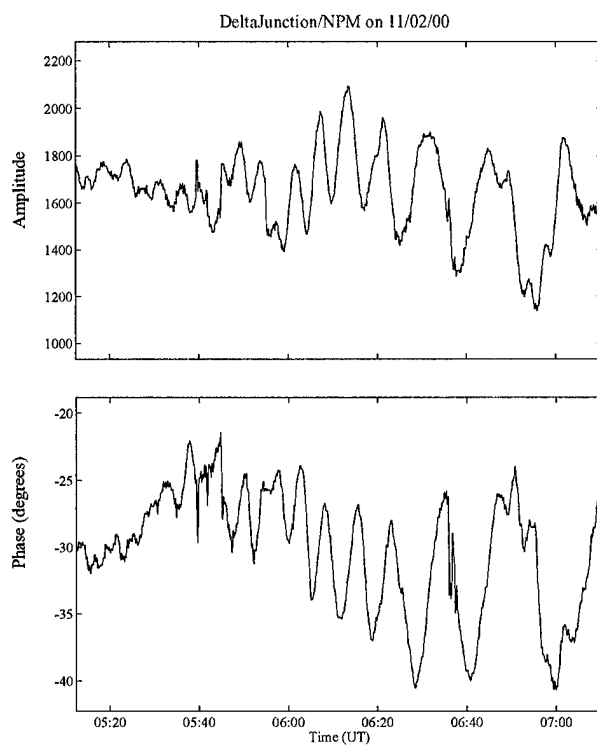
As mentioned above, results of the atmospheric gravity wave study were reported in a paper delivered at the December American Geophysical Union in 1998 [Demirkol, M. K., U. S. Inan, and T. F. Bell, Quantitative determination of D-region density and temperature profiles via inversion of sub-ionospheric VLF measurements, *EOS*, 79, F674, 1998]. A number of typical examples of gravity wave events were observed on November 2000 at the Delta Junction VLF receiving site. Some of these events involved the subionospheric signal from the NPM transmitter. Figure 1 shows the path of the VLF signal from the NPM transmitter in Hawaii as it propagated to the VLF receiving site at Delta Junction in Alaska. Delta Junction is located at a position close to the auroral electrojet where gravity waves are often generated.



**Fig. 1. Propagation path of the NPM VLF signal from Hawaii across Alaska to the Delta Junction (DJ) VLF receiving site. The footprints of the magnetic shells  $L = 4$  and  $7$  are indicated by dashed lines.**

Figure 2 shows the amplitude and phase of the sub-ionospheric NPM signal as observed at

Delta Junction during the period: 0510 UT to 0710 UT. Quasi-sinusoidal oscillations in both amplitude and phase are observed as a gravity wave moves across the NPM propagation path. The largest amplitude change due to the gravity wave is approximately 3 dB. The maximum phase change is approximately 15 degrees.



**Fig. 2. The upper and lower panels show respectively the amplitude (in normalized units) and the phase of the NPM sub-ionospheric VLF signal as observed at Delta Junction.**

## **5. List of personnel contributing to report**

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